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Comparative Investigation on Mechanical Properties of Banana and Sisal Reinforced Polymer Based Composites

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Abstract

In this work, sisal fiber and banana fibers have been used as the main reinforcing materials with epoxy resin as the matrix in order to increase the effectiveness of natural fibers. It is envisaged to fabricate synthesis and study the Banana and Sisal Fiber as a reinforced material in polymer matrix composites .The natural composites were fabricated by hand layup method. The mechanical and physical properties have been studied for both the fibers by changing the orientation as uni-directional and bi-directional pattern with epoxy resin as a matrix material. Initially optimum fiber length and weight percentage were determined. The tensile, impact, flexural, water absorption tests have been performed on these fabricated composites. Morphological analysis was carried out in tensile sample composites using SEM to analyze the fracture mechanism of the both the fibers.

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*Keywords:*Natural Fibers;Sisal Fibers;Banana Fibers;Composite materials;Epoxy Resin

1. Introduction

With growing environmental awareness and ecological concerns of the natural fibers polymer composites have attracted the attention of many researchers and scientists due to their advantages over conventional glass and carbon fibers. The interest in natural fiber reinforced polymer composites is rapidly growing both in terms of their industrial applications and human applications .The various advantages of natural fibers over manmade synthetic fiber are cheap , renewable, completely or partially recyclable , and bio degradable . The natural fiber composites include

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flax, hemp, jute, sisal, kenaf, coir, kapok, banana, henequen and many others. Geethamma et al. (1998) reported that composite materials are suitably applicable for aerospace, leisure, construction, sport, packing and more suitable for automotive industries. The use of natural fibers reduces weight by 10% and lowers the energy needed for production by 80%; while the cost of the component is 5% lower than the comparable fiber glass-reinforced components.The properties of natural fiber reinforced composites are mainly influenced by fiber content and amount of filler. Mechanical properties of banana fiber were studied by Kulkarni et al. (1983).Sreekala et al. (2002) investigated the performance of mechanical properties of oil palm fiber with glass fiber and used phenol formaldehyde as a resin. The investigation revealed that maximum mechanical performance occurs at 40 weight % loading .Venkateshwaran et al.(2012) reported that sisal/banana hybrid natural fiber composite specimens were prepared with different ratios by taking 0.4volume fraction and tensile properties of these hybrid natural fiber composites are also examined using rule of mixtures (RoHM) . Yan Li et al. (2000) reported that sisal fiber was the promising reinforcement because of low density, high specific strength, no health hazards and finding applications in making of ropes, mats, carpets, fancy articles etc. The objective of their study is to investigate the effect of fiber loading on rheological properties and the physical-mechanical properties of a dry rubber compounds. Venkateswaran et al. (2011) reported that the hybridization of sisal fiber with banana /epoxy composites up to 50% by weight increases the mechanical properties and also decreases the water absorption properties. The overall tensile and flexural properties of natural fiber reinforced polymer hybrid composites are highly dependent on the aspect ratio, moisture absorption tendency, morphology and dimensional stability of the fibers used. Natural fiber exhibit superior mechanical properties such as flexibility, stiffness and modulus compared glass fibers investigated by Goulart et al. (2011). Flavio et al. (2010) opined that natural fibers such as sisal and jute fibers are replacing the glass and glass and carbon fibers owing to their easy availability and cost. George et al. (1990) observed that the stability of the composite compared to sisal fiber may be due to improved fiber –matrix interaction. Therefore, suitable processing techniques and parameters must be carefully selected in order to yield the optimum composite products. Our research work aims to study the effect of fiber loading, chemical treatments, manufacturing techniques and process parameters on the tensile properties of natural fiber reinforced composites. Comparisons are made on both the reinforcement materials such as banana and sisal fiber polymer composites so as to study the mechanical and physical properties of composites. In short the main objective is to develop a low cost natural fiber based composite that can be used for commercial applications.

2. Experimental details

2.1. Materials

Sisal fiber is a natural fiber of Agavaceae (Agave) family a type of leaf fiber is extracted from sisal plant leaves traditionally used for making ropes and twine. Banana fiber comes from family name (Musaceae) family a type of bast fiber, extracted from the banana tree. Epoxy Resin [LY556] and Hardner [HY591] is used as a reinforcement material. The LY556 resin is a bi-functional epoxy resin i.e., diglycidyl ether of biphenyl-A (DGEBA0, while HY591 is an aliphatic primary amine, i.e., triethylene tetramine (TETA).The properties of banana and sisal fibers are given in Table 1 [4].

2.2. Banana Fiber Extraction

Mature banana pseudo-stem was obtained from farm, and was cut into length of 500 mm sliced longitudinally into four pieces and each was totally submerged in water for15days, after which the stems were removed from the water and were loosened by swishing back and forth in a pool of tap water .They were subsequently sun dried for eight hours and further loosened by manual combing. The extracted fibers were then treated with 5% sodium hydroxide (NaOH) solution for four hours, under total immersion condition to avoid oxidation of the fiber, after which it was washed in overflowing tap water until neutral pH is attained. The treated fibers were then dried in an oven for 24 hours at 105 ^{0}C in order to remove free water, then cut to required dimensions and stored in an air tight container. The properties of banana fiber are given in Table 1.

2.3. Sisal Fiber Extraction

Sisal leaves was obtained from farm , and was cut into length of 500 mm sliced longitudinally and were chopped and cleaned using a benzene –ethanol mixture in a 2:1 liquid ratio by volume. Sisal fibers were soaked in (NaOH) solution of desired concentration while heated at 80 ^{0}C and stirred for 90 minutes. Pre- treatment of sisal with (NaOH) can partially remove lignin and hemicelluloses, and certainly results in weight loss of the fibers. To quantify the amount of material removed , the alkali treated products were filtered and washed with distilled water to pH value 6 and then dried under vacuum at 60 ^{0}C to remove free water, and cut to required dimensions and stored in a air tight container. The properties of sisal fiber are given in Table 1.

Table 1. Properties of banana and sisal fiber

Properties	Banana fiber	Sisal fiber
Cellulose (%)	62-64	65
Hemi cellulose (%)	19	12
Lignin (%)	5	9.9
Moisture content (%)	10-11.5	10
Density (g/cm^3)	1.35	1.45
Flexural modulus (GPa)	2-5	12.5-17.5
Microfibrillar angle	11	20
Lumen size (mm)	5	11
Tensile strength (MPa)	54	68
Young-s modulus (GPa)	3.48	3.77

2.4. Preparation of epoxy and hardener

Epoxy LY556 of density 1.15-1.20g/cm ^{3}, mixed with hardener HY951 of density 0.97-0.99 g/cm ^{3} is used to prepare the composite plate. The weight ratio of mixing epoxy and hardener is 10:1. Resin was purchased from local sources.

2.5. Mould preparation

Mould is fabricated with a mallex sheet of 50*50 cm size and rubber block piece is pasted on the dimensions 300 mm × 300 mm on four sides. The fabrication was carried out through hand layup technique. Before lay-up process the mould had been applied with a releasing agent to insure that the art will not adhere to the mould .The top and bottom lates were covered with mallex sheet and the fibers were with epoxy compressed to avoid the debris from entering into composite parts during curing.

2.6. Fabrication of composites

Banana Fibers and sisal fibers were taken separately for both uni-directional and bi-directional for the sample preparation .The fiber weight percentage for both the orientation were taken as 12% .The epoxy resin and hardener were mixed in the ratio 10:1 arts and it was stirred with simple mechanical stirring. The moulds were cleaned and dried before applying epoxy resin. The fibers were laid uniformly over the mould before applying releasing agent. The fibers were than uniformly compressed for few minutes to remove the shrinkage in the fiber. Then both the fibers were removed from the mould. The releasing agent was applied over the mould, after which a coat of epoxy was applied. The compressed fiber is placed over the epoxy coat, ensuring uniform distribution of fibers of two orientations such as uni-directionally and bi-directionally. The epoxy mixture was then poured over the fiber uniformly and compressed for a curing time of 24 hours. After the curing process, test samples were cut to the required sizes as prescribed in the ASTM standards. The photographs of the fabricated natural composite samples are shown in Fig 1(a) and 1 (b).

Fig. 1. (a) fabricated banana fiber samples; Fig. 1 (b) fabricated sisal fiber samples.

2.7. Characterization and properties

2.7.1. Mechanical tests

The bonding at the fiber matrix interface plays a major role in the mechanical behaviour of composite materials. In polymer matrix composites the most important function of the matrix is to distribute the applied stress among the fibers. The applied stress must be transferred across the fiber/matrix interface, transverse, longitudinal, shear strength of a polymer matrix composite depend heavily on the interfacial bond strength. Thus bonding must be maximized if the full strength of reinforcing fiber is to be realized, making accurate characterization of interfacial bonding in composite materials. Aerospace applications of advanced composites increase for about 50 percent of current sales. Sporting goods, such as golf clubs and tennis rackets, increases an account for another 25 percent. Automobiles and industrial equipments are manufactured using polymer matrix composites .The next major challenge for polymer matrix composites is used in large military and commercial transport aircraft. Polymer matrix composites are used in commercial aircraft, to reduce the weight of the aircraft. The Polymer matrix composites are in the automobile for production of body panels, drive shafts, and leaf springs. Because of their resistance to corrosion, they may also be attractive for marine structures. In space, a variety of composites could be used in the proposed aerospace plane, and Polymer matrix composites are being considered for the tubular frame of the NASA space station. Research and Development Priorities unlike most structural ceramics, Polymer matrix composites have compiled an excellent service record, particularly in military aircraft.

2.7.1.1. Tensile tests

The mechanical behavior of the composites prepared with the fabricated samples was tested in the Universal Tensile testing machine with testing load range of maximum 5 Ton with gear rotation speed of 1.25,1.5,2.5 mm/min. The experiments were conducted at normal room temperature .The test specimens were cut as per ASTM standards using water jet machining. The tensile strength was determined as per ASTM D638 with standard gauge length of 50mm, with a cross head seed of 1.25 mm/min.

2.7.1.2. Impact tests

Impact strength of the composite specimens was carried out in Izod impact testing machine according to ASTM D256 standard. The specimen size was 65.5*12.7*3 mm with depth under notch of 2.5mm .The Charpy impact test, is a standardized high strain rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent ductile-brittle transition.

2.7.1.3. Flexural tests

The flexural test measures the force required to bend a beam under three point loading situations. The three point bending test was performed in accordance with ASTMD 790 standards .The samples was cut into50.8*12.7*3 mm respectively. The data is often used to select elements for parts that will support loads without inflection. Flexural modulus is used as an indication of a material's stiffness when inflection. Since the physical properties of many elements can vary depending on ambient temperature, it is appropriate to test materials at temperatures that simulate the intended end use environment.

2.7.2. Physical tests

2.7.2.1. Hardness tests

The physical behaviour of the samples was calculated using hardness tests. The hardness test was calculated in Rockwell testing machine .The testing machine can withstand a maximum load of 60 Kg and with a minor load of 10 kg. In each case three specimens were examined and the average value is obtained.

2.7.2.2. Water absorption tests

The water absorption characteristic is another significant property for natural fiber composites since they are applied in automotive, aerospace and marine applications. The water absorption test was carried out as per ASTM standard D570 tests with specimen size of 25*25*3 mm.

2.8. Scanning electron micrographs

Scanning electron microscope (SEM) was employed to investigate the morphology of the different types of fibers which are oriented uni-directionally and bi-directionally. The SEM was taken on two parameters such as ordinary fabricated specimen on both the orientation of two fibers and a fractured piece of the specimen during tensile test. In the first instance, the specimens were platinum coated using Auto fine coater. The specimen was coated with platinum because it is a non conductive material. The specimen were mounted on the specimen holder and a applied tension of 10kV is passed .Interfacial properties , such as fiber matrix interaction , fracture behavior and fiber pull out of samples after mechanical tests were observed .

3. Results and discussion

The tensile, flexural, hardness and impact properties of banana and sisal fibers are furnished in Table 2.

Table 2. Tensile, Flexural, Hardness and Impact properties of banana and sisal fibers

Fiber orientation	Impact strength kJ/m^2	Tensile strength MPa	Flexural strength MPa	Hardness L scale	Flexural modulus MPa
Sisal 90	1.3	56.5	371.33	103.533	26.437
Banana 90	2.5	20	126.67	106.366	33.53
Sisal 0,90,0	1.35	16	96.375	91.566	10.51
Banana 0,90,0	2.8	32.5	320.625	103.2	33.49

3.1. Mechanical properties of sisal and banana fiber

The most significant factor which determines the strength of the fiber reinforced composite is the bonding between the matrix and the fiber. Since epoxy resin is bonded between banana and sisal fiber, the affinity for moisture absorption of natural fiber is more than synthetic fiber. Further the mechanical properties of natural fiber composites depend on many parameters such as fiber strength, modulus, fiber length and orientation; in addition to fiber matrix interfacial bond strength .Fiber matrix interface plays a vital role between matrix and reinforcement. A good fiber interfacial results in better bonding strength, effective stress transfer from matrix to the fiber.

3.1.1. Tensile strength

Figure 2 shows the results of tensile strength of banana and sisal fibers .The tensile strength of sisal 90 degree orientation exhibits higher tensile strength than banana fiber both in the unidirectional and bi directional orientation. The maximum tensile strength of 56.6 MPa is obtained in sisal fiber with 90^{0} orientation. Venkateshwaran et al. (2011) stated that maximum tensile properties is obtained in 5 mm fiber length and 12 % weight percentage .

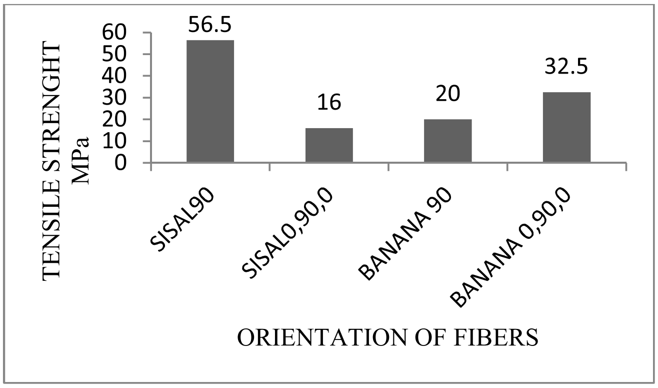

Fig. 2. variation of tensile strength for different fiber orientation

3.1.2. Flexural strength

The results of Flexural strength and flexural modulus of banana and sisal fibers are depicted in Fig 3 and 4.The flexural strength of sisal fiber is 371.33 MPa exhibits higher than banana both in the uni directional and bi directional orientations .However the flexural modulus of banana 90 degree is 33.53 MPa which is higher than that of sisal fiber. Joseph et al. (2003) attributed the increase in the flexural strength and modulus to the increasing fiber contact.

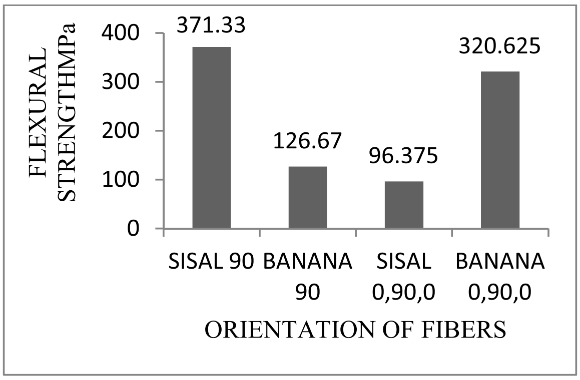

Fig. 3. variation of flexural strength for different fiber orientation

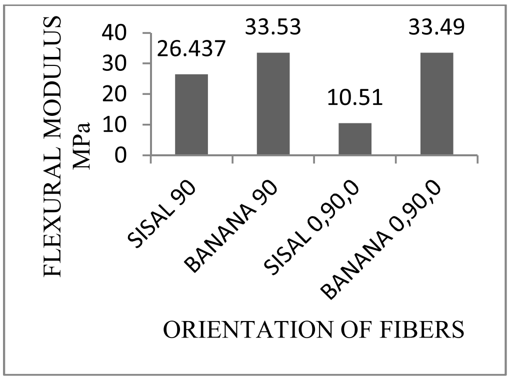

Fig. 4. variation of flexural modulus for different fiber orientation

3.1.3. Impact strength

Figure 5 shows the result of Impact Test which was performed according to ASTM D256 standard. The specimen size was 65.5mm(Length),12.7mm(Width),3mm(Thickness) with depth under notch of 2.5mm.The tests revel that banana fiber with bi directional orientation has higher impact strength than sisal fiber and banana fiber with bi directional and uni directional respectively .

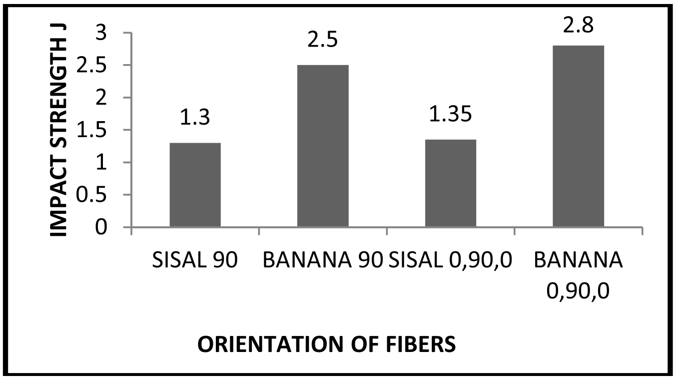

Fig. 5. variation of impact strength for different fiber orientation

3.1.4. Hardness tests

The hardness tests were conducted in Rockwell L scale testing machine. The major load applied was 60 Kg and the minor load was 10 Kg. The test shows that banana fiber can withstand higher impact load than sisal fiber.

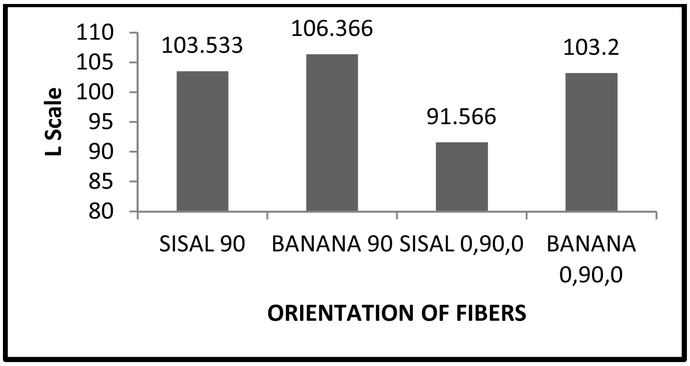

Fig.6. hardness variation for different fiber orientation

3.2. Physical properties of sisal and banana fiber

3.2.1. Water absorption tests

The water absorption tests were performed on the two samples in three different conditions such as sea water, ordinary tap water, and distilled water. The water absorption test was carried out as per ASTM standards D 570 specimen size of 25*25*3 mm. The water absorption test was carried in three types of water such as ordinary tap water, sea water, distilled water .The samples were uniformly dried at 70^0 C for 24 hours. Then the specimens were weighed to an accuracy of 0.001g.Water absorption tests were conducted by immersing the composites specimens in ordinary tap water, sea water, distilled water in a plastic tub at room temperature for a period of 14 days time interval. After 14 days time interval, the samples were removed from water carefully blotted to remove the excess water on the surface and wiped with a clean cloth and the specimens were immediately weighed 0.001g. The moisture absorption was calculated by the weight difference of the samples. The percentage of water absorption of three samples was calculated according to the formula.

$$\%Water\ Absorption= \{(M_W-M_A)/M_A\}*100 \quad (1)$$

Where M_W and M_A are the wet samples and dry samples

The results clearly reveal that the percentage of water absorption is higher in sisal fibers than banana fibers. The % of ordinary water is higher than distilled and sea water. The results are expressed in figure 7 and Table 3.

Table 3. Water Absorption Tests.

Fibers orientation	% of ordinary water absorption	% of distilled water absorption	% of sea water absorption
Sisal 90	4.07	3.92	3.55
Banana 90	3.65	3.43	3.31
Sisal 0,90,0	2.96	2.41	2.10
Banana 0,90,0	2.50	2.31	1.76

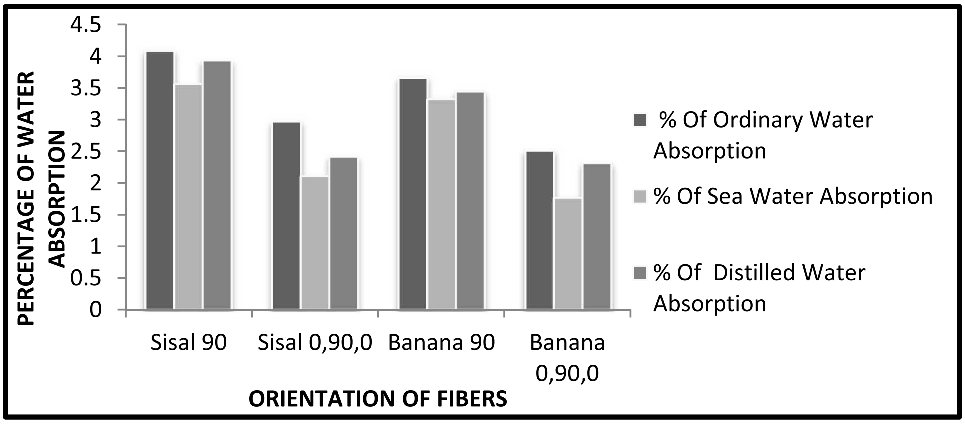

Fig. 7. percentage of water absorption for different fiber orientation

3.3. Morphological study

3.3.1. Scanning Electron Microscope

The failure morphology of the fabricated composites after tensile testing was examined through scanning electron microscope. The SEM images of the samples underwent of tensile test is presented. The fracture takes place in the specimen by the application of uni-axial tensile load .The fracture indicates the fiber fracture and pull out from the specimen and also the dislocation of fibers. The SEM image of the produced samples is presented in fig.8 (a). The fig 11 (a) clearly revels that the adhesion between the banana fiber is better than sisal fiber fig 9(a). The Fig 8 (b) reveals that fiber pull out occurs on sisal 90 ^{0} orientation occurred to a greater extent than sisal bi directional samples as shown in Fig 9 (b).All the SEM micrographs indicate the phenomenon of pull out occurred to a greater extent in sisal fibers than banana fibers .The image analysis also shows that epoxy resin is well bonded with banana fibers than sisal fibers which results in failure of sisal fiber to a greater extent than banana fiber. Poor interfacial bonding between fiber and matrix from Fig 8 (a) resulting in low impact strength and hardness properties.

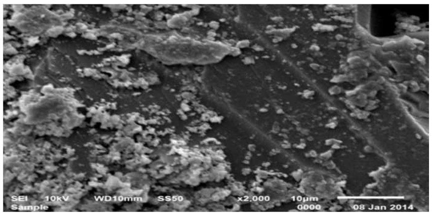

Fig. 8. (a) sisal 90 before fracture.

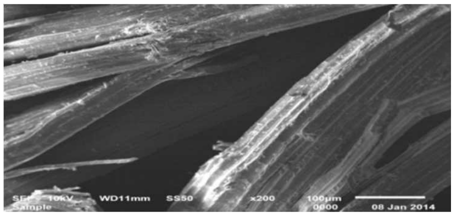

Fig. 8. (b) sisal 90 after fracture.

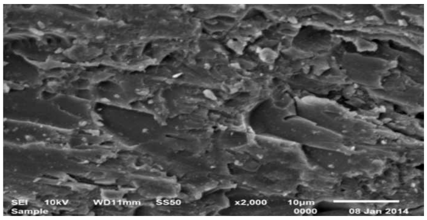

Fig. 9. (a) sisal 0,90,0 before fracture

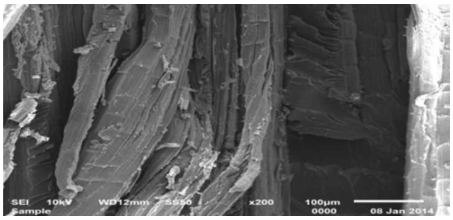

Fig. 9. (b) sisal 0,90,0 after fracture.

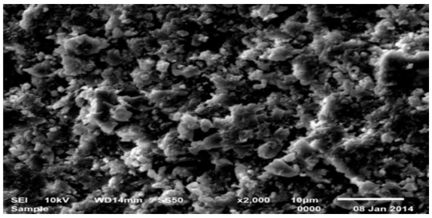

Fig. 10. (a) banana 90 before fracture.

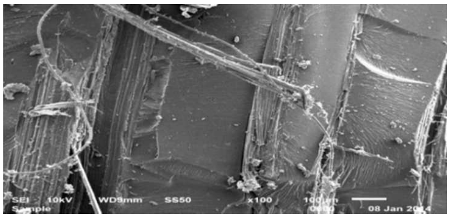

Fig. 10. (b) banana 90 after fracture.

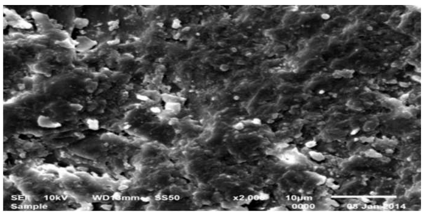

Fig. 11. (a) banana 0,90,0 before fracture

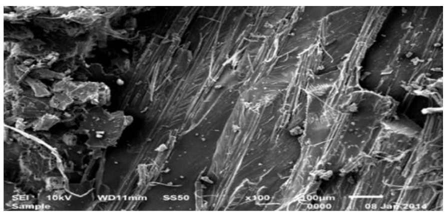

Fig. 11. (b) banana 0,90,0 after fracture.

4. Conclusions

Epoxy based sisal fiber and banana fiber composites were fabricated by hand lay-u process. After testing and characterization the following observations are made from this study follows:

The comparison of tensile strength reveals that sisal 90 ^{0} orientation fiber/ epoxy composite has 56.5 MPa exhibit higher tensile strength than sisal bi directional fiber 16 MPa. Whereas banana bi directional fiber/epoxy composite has exhibit better tensile strength of 32.5 MPa than banana uni directional fiber which has only 20 MPa. From the results it is observed that sisal fiber/epoxy has better tensile strength than banana fiber. When fiber concentration increases the tensile strength also increases.

Impact tests reveal that banana fiber / epoxy uni directional and bi directional posses higher impact strength than sisal fiber on both the orientations.

The flexural strength of sisal fiber/ epoxy uni directional exhibits better flexural strength of 371.33MPa than banana fiber. The banana fiber/ epoxy bi directional composite exhibits 320.625 MPa where as to sisal fiber/ epoxy bi directional has only 96.375MPa.

The hardness tests reveal that banana fiber / epoxy uni directional and bi directional can withstand higher impact load than sisal fiber on both the orientations.

Water absorption test are analyzed based on both the orientation of fibers and on three different types of water with same intervals of time. The sisal fiber/epoxy absorbs more water than banana fiber/ epoxy. The percentage of ordinary water absorbs more than compare to distilled and sea water.

The morphological study reveals that fibers pull out are occurred on unidirectional fibers than bi directional fibers. From the figure 9(a) and 11(a) epoxy resin are well bonded in bidirectional fibers than uni directional fibers which results in weak interfacial bonding on sisal and banana 90^0 orientation fibers.

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